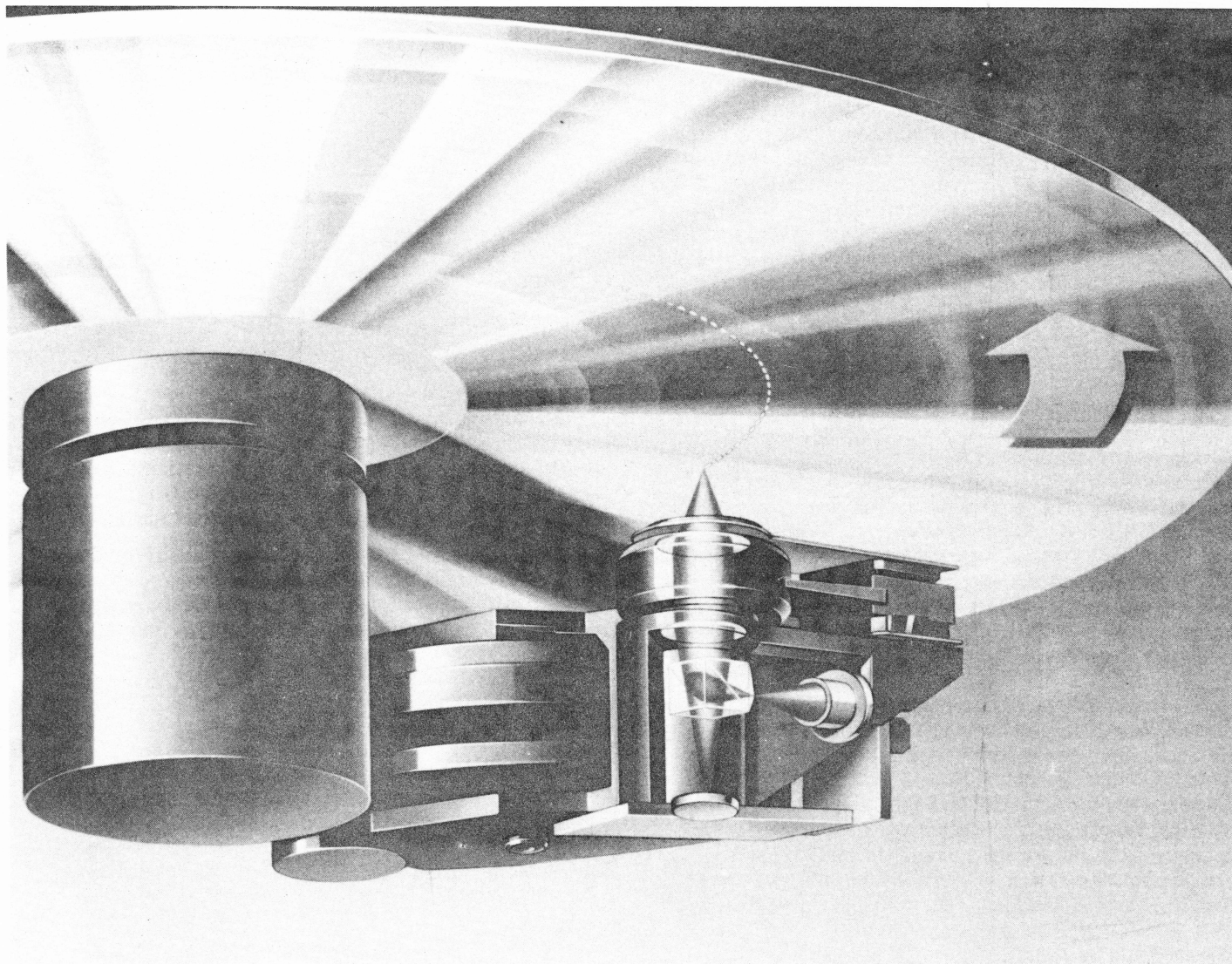


CD single-beam laser

November 1986



Philips Compact Disc

The advantages of the Philips single-beam laser technique

Philips Compact Disc players have always used a single-beam laser optical pick-up in preference to the widely used 3-beam technique. And the 'push-pull' method chosen to obtain the required information uses very simple optics and mechanics (though in conjunction with highly sophisticated, highly integrated electronics).

Philips players have won many awards for sound quality and operating convenience. Perhaps they are proof enough of the merits of the Philips laser. But there are strong technical arguments too, for the Philips technique. They are given briefly here.

The Three Functions of the Optical Pick-Up

The primary task of the optical pick-up is to retrieve the digital audio data from the Compact Disc. This data includes timing information which is used to maintain the correct drive motor speed. But there are two further tasks: to provide focusing and tracking signals. To detect the pit pattern on the disc, the laser beam must be kept in focus on a track which is only 0.6 micron wide, at a pitch of 1.6 micron. The diameter of the focal spot must be maintained between 0.5 and 1.5 micron, and the radial tracking must be accurate within 0.1 micron of the centre of the track. The two signals to achieve this must come from the optical pick-up.

audio products

There are, however, complications. Any tiny flaw in the reflective surface, produced during manufacture, obliterates part of the pit pattern. Some of such flaws are inevitable. And although fingerprints and scratches on the surface of the disc cannot damage the pit pattern, they can, if severe enough, hide it. In addition, the mechanical tolerances of the disc and the player are large in relation to the track dimensions.

Eccentricity can be as much as 0.6 mm, and the disc is never perfectly flat; unevenness may be as much as 0.5 mm. The quality of the sound, and the accurate location of music passages, therefore, depends heavily on the tracking and focusing abilities of the optical pick-up.

The Three-Beam System

The first system developed for the optical pick-up used three beams; a main beam for information read-out and focusing, and two auxiliary beams for radial tracking.

This system, though complex both optically and mechanically, was well suited to the analogue LaserVision system for which it was originally designed. It is less suitable for Compact Disc, in particular because of the LF components present in Compact Disc eight-to-fourteen modulation tend to cause cross-talk from adjacent tracks in the focusing and tracking servos.

There are further constraints on 3-beam systems. Linear tracking, with precise beam alignment, is essential. Any misalignment of the auxiliary beams during the life of the player will degrade the performance, although wear and tear are unavoidable if such a complex mechanism is used intensively. Furthermore, since the beam is split into three, only part of the light supplied by the laser is available for data read-out. Since the difference in the light intensity from the pits and flat areas of the disc (the modulation index) is only about 20%, this is a very important consideration. It explains why three-beam lasers are vulnerable to scratches and fingerprints.

Nevertheless, three-beam systems are commonly used, in particularly in Japanese Compact Disc players. They generally have a two-stage movement. The whole optical assembly is moved radially across the disc by, for example, a lead screw, and the actual tracking is done by moving the objective lens. In this situation, the thread of the lead screw is necessarily a compromise between the fine thread required for normal playback tracking at about 35 mm per hour, and the coarse thread required for fast feed at about 35 mm per second.

Single-Beam Systems

The optics and mechanics of single-beam systems are inherently simpler than those of 3-beam systems. The performance depends on how effectively the data, tracking and focusing functions are separated and processed in the electronics.

From the data read-out point of view, single-beam systems have the important advantage that all the light from the laser is available for reading the signal. This provides potential for higher sound quality and lower sensitivity to fingerprints and scratches. Various tracking and focusing techniques can be applied in single-beam systems.

Tracking techniques include push-pull, differential phase detection or heterodyne, and HF wobble. Focusing techniques include astigmatic (cylindrical lens), Foucault (knife edge) and critical angle.

Push-pull tracking with Foucault focusing is a popular combination, while differential phase detection tracking with critical angle focusing is also used. The involved switching required by the latter combination has severely restricted its use.

Push-Pull Tracking with 'Wobble'

The track on a compact disc forms a virtual raster, which produces diffraction of the laser beam, both tangentially and (important for tracking) radially. The degree of diffraction depends upon the 'order' of the light. 'Zero order' light is not diffracted at all, 'first order' light is diffracted through an angle proportional to the light frequency, 'second order' light through an angle proportional to twice the light frequency, and so on. In practice, only the zero order and part of the first order light return through the pupil of the objective lens, higher orders being too widely spread. The optics are 'diffraction limited'.

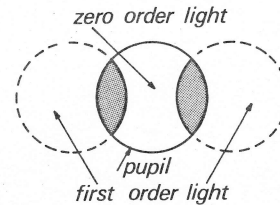


Fig. 1

Overlapping of zero and first order light in the pupil

Within the pupil, zero and first order light overlap (Fig. 1). In the overlapping region, interfaces can occur. Under specific conditions, therefore, the pattern of the light in the pupil depends on the position of the beam relative to the track (Fig. 2).

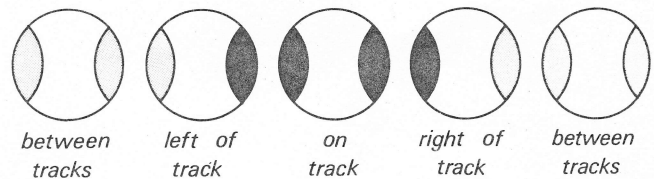


Fig. 2

Tracking: Light patterns in the pupil

Push-pull tracking measures the light difference in the two halves of the pupil and applies a corresponding radial movement to the laser assembly.

This 'push-pull' method depends on the two effective halves of the pupil being exactly equal and the light beam being exactly perpendicular to the disc. If not, an offset error arises, and the correction signal moves the beam, not to the centre of the track, but to one side of it.

In the Philips tracking system, offset error is eliminated by a low-frequency 'wobble' signal that wobbles the beam to and fro across the centre of the track. The total reflected light now has a wobble component that varies in frequency and in phase according to the position of the beam relative to the centre of the track (Fig. 3).

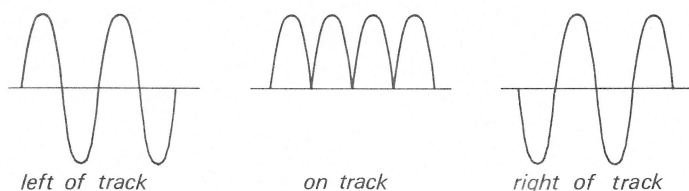


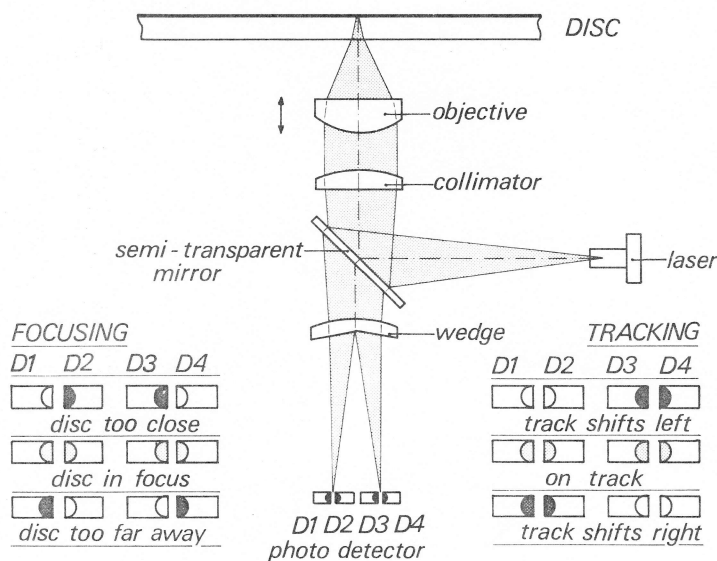
Fig. 3
Wobble components in the reflected beam.

The combination of 'push-pull' and 'wobble' is an economical means of tracking. And it produces results which, in terms of sound quality and speed of access, have not been equalled by other means.

Philips Single Beam Optics

The Philips optical pick-up uses a special version of push-pull tracking with a low-frequency wobble for high resolution tracking, together with Foucault focusing.

The optics required for this combination are very simple. In the new CDM 2 pick-up assembly (Fig. 4), the laser point source is focused by two single-element lenses as a diffraction-limited spot on the information layer of the disc. The single-element spherical collimation lens and the single-element aspherical objective lens are in fact combined. A plastic aspherical skin is applied to the glass spherical body by a replica technology process specially developed by Philips.

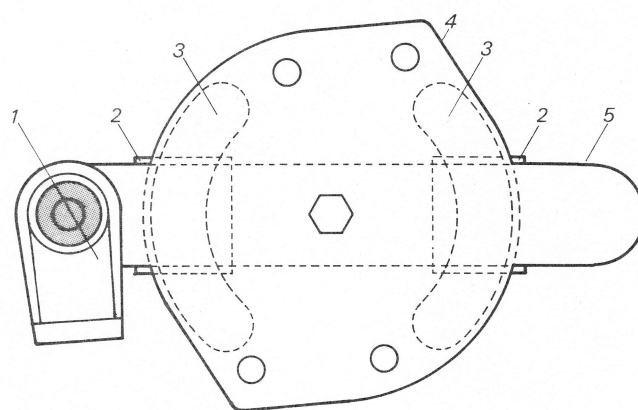


SINGLE BEAM PICK UP

Fig. 4
Illustrations showing CDM 2 pick-up assembly and principles of Philips tracking and focusing

In addition to the new lens technology, the geometrical arrangement is new, the positions of the laser and photodetector having been interchanged. Furthermore, an inexpensive semi-transparent mirror is used instead of a beam-splitter cube. This introduces astigmatism. A wedge in the light path cures this, and simultaneously divides the beam into the two halves used to generate the tracking and focusing error signals. The reflected astigmatic beam could be used to generate the error signals directly (astigmatic focusing in combination with push-pull tracking). But Philips investigations show that noise and crosstalk in the error signals derived in this way are higher and degrade performance.

In the CDM 2 optical system, the only adjustment required during assembly is the horizontal orientation of the photo detector.



1. pick-up
2. coil
3. magnet
4. bearing assy
5. arm

Fig. 5
Diagrams of linear motor.

Swinging-Arm Mechanics (Fig. 5)

The Philips pick-up (1) is mounted at the end of a low-inertia balanced arm, pivoted in the middle. Together with a permanent magnet (3), a coil (2) housed in the arm (5) forms a linear motor. This is used both for tracking and for fast-feeding the pick-up across the disc. The pick-up can be directed very quickly to any track, a full sweep across all tracks taking less than one second. Track following is accurate to within 0.1 micron of track centre. Eccentricities up to 0.6 mm ($100 \times$ the width of the track) can be followed because the whole pick-up moves rather than just the objective, and there is no vignetting. With the arm pivot as the only moving part, the mechanism is extremely reliable and wear is minimal. Shock sensitivity, too, is at least as good as with linear tracking, with less sensitivity to the translational forces associated with everyday bumps.

Single-beam/swinging arm versus three-beam/linear arm: A comparison

Single-beam

Mechanics

Choice of simple swinging arm or sledge

Alignment not critical

Low wear

Low sensitivity to wear

Optics

Simple, very few components

Horizontal adjustment only

Insensitive to ageing and alignment

Error signal properties

No interference in radial error signal from EFM LF component

On swinging arm, can follow very large eccentricities

Electronics

Philips servo electronics complex, but not critical because of automatic offset cancellation and automatic gain control

Three-beam

Mechanics

Complex (2-stage) sledge, with lead screw and moving mirror

Precise alignment needed

Liable to wear

Sensitive to wear

Optics

Complex, several components

A number of critical adjustments

Sensitive to ageing and alignment

Error signal properties

Radial error signal prone to interference from EFM LF component

Difficulty in following large eccentricities because of vignetting (only objective moves)

Electronics

Relatively simple electronics, but usually requiring several critical adjustments